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Objective Forecasts of Precipitation Using PE Model Output

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Eastern Region

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UNITED STATES DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU EASTERN REGION
Garden City, New York

WEATHER BUREAU TECHNICAL MEMORANDUM ER-35

OBJECTIVE FORECASTS OF PRECIPITATION USING PE MODEL OUTPUT

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Eastern Region Headquarters
Scientific Services Division
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ABSTRACT

The National Meteorological Centers Primitive Equation (PE) Model predictions of relative humidity, relative humidity trend and vertical velocity are found to be well correlated to frequency of observed precipitation at New York City during the period November through March. A technique is developed for using these PE predictions to objectively forecast probability of precipitation (PoP). The technique is shown to have applications to other areas.

Objective Forecasts of Precipitation Using PE Model Output
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INTRODUCTION

Techniques for preparing objective probability of precipitation (PoP) forecasts from the Primitive Equation (PE) multilayer moisture model (1) output have appeared in technical attachments to the U.S. Weather Bureau Eastern Region Headquarters Staff Notes. Techniques developed for Raleigh, N. C. (2) and for Astoria, Oregon (3) use as predictors PE forecast values of relative humidity and vertical velocity extracted from facsimile maps. The technique developed for Raleigh also uses as a predictor, the forecast trend of relative humidity. Since PE predictors that appear on facsimile maps extend out only to 36 hours, objective schemes developed using facsimile map presentation of the predictors do not apply to the third forecast period in the public weather forecast. PE predictors out to 48 hours would be required to accomplish that. A technique developed for New York City (4) enables an objective PoP forecast to be made for all three forecast periods in the public weather forecasts, but this technique is limited in use to only those occasions when the PE model actually forecasts a quantity of precipitation to occur at JFK, as indicated in the FOUS-1 teletype message (5). The final paragraph in the New York City study suggests that for the cases in which the PE quantitative precipitation forecast (QPF) does not indicate precipitation (and even when it does), PoP forecasts can be generated from PE model output by using objective techniques that relate frequency of precipitation to PE relative humidity and vertical velocity forecasts. It is the purpose of this paper to present such an objective technique. The technique is developed specifically for New York City (but will be shown to have more general application) and for the last two of the three 12 hour periods in the public weather forecast prepared during the cold season of the year, defined here as November through March. The PE predictors used are taken from the FOUS-1 message which extends out to 48 hours and is transmitted on teletypewriter circuit "C" twice daily, currently at about 0644Z and 1844Z.

The PE multilayer moisture model became operational in the Weather Bureau at 0000Z October 29, 1969. Programming errors in the model were removed as of 1200Z November 4, 1969. Modifications were introduced into the PE model on March 19, 1970 (6). A half month of verification by the Techniques Development Laboratory on cases after the modifications were made indicated little or no difference in the PE QPF categorical forecasts over the eastern United States, at least during the first 24 hours of the forecast (7). While it is doubtful that the modifications made on March 19, 1970 significantly affect utilization of the results presented here, any future modifications in the PE model could affect these results.

Procedure

PE forecasts used in this study are those that appeared in the FOUS-1 messages for JFK during the period November 5, 1969 through March 31, 1970. Precipitation observations used were those made at LaGuardia Airport, New York, the closest Weather Bureau observation point to the geographical center of New York City.

A forecaster receives the FOUS-1 message about seven hours after the time of initial data used to generate the PE forecasts. Because of this time lost in data handling and communications, the PE model output for hours 24 to 36 after initial data time corresponds exactly to the second 12 hour period in the forecast released to the public soon after the FOUS-1 message is available. Similarly the PE model output for hours 36 to 48 corresponds exactly to the third 12 hour period in the public weather forecast. Technical Procedures Bulletins Number 30 (5) and Number 49 (10) describes the FOUS-1 and FOUS-2 teletype 6-hourly message format and the parameters contained in the message. Briefly, the PTT group shown for output hours 30 plus 36 indicate PE QPF corresponding to the second 12 hour period in the public forecast and PTT shown for hours 42 plus 48 indicate PE QPF for the third 12 hour period. For all other predictors except the PTT group, output for hours 24, 30 and 36 in the message indicate PE predictions for the beginning, middle and end of the second period in the public forecast and output for hours 36, 42 and 48 indicate PE predictions for the beginning, middle and end of the third period in the public forecast. The relative humidity forecast used in this study and provided in the FOUS-1 message is the mean relative humidity of the lowest three layers of the PE model, in percent. The lowest three layers extends from the surface to about 500mb. The vertical velocity forecast in the message pertains to the vertical velocity at 700mb., in tenths of a microbar per second averaged over two hours, centered at the forecast hour indicated in the message.

Contrary to what is written in Technical Procedures Bulletin Number 30, the vertical velocity forecast that appears in the FOUS-1 (and FOUS-2) message is a weighted average equal to 1/2 of the vertical velocity forecast valid at the indicated time plus 1/4 of the vertical velocity forecast valid one hour earlier, plus 1/4 of the vertical velocity forecast valid one hour later then the indicated valid time. The vertical velocity forecasts that appear on facsimile charts are determined by using an averaging scheme which is the normal of 6 vertical velocity forecasts, each validating 20 minutes apart (every other 10 minute time step) prior to and including the forecast valid at the valid time shown on the facsimile chart (8).

In this study the PE forecast values applicable to the beginning and end of the second and third public weather forecast periods are examined to determine the highest relative humidity and highest algebraic values of vertical velocity expected in these periods. Also the relative humidity forecast at the end of each forecast period, minus the predicted relative humidity 12 hours earlier, at the beginning of the forecast period, is determined and defined as the predicted relative humidity trend in the forecast period. The PE relative humidity and vertical velocity forecasts verifying at hours 30 and 42 and applicable to the middle of the second and third forecast periods were not used. Smoothing techniques required in working with a small data sample make it improbable that consideration of the PE forecasts valid at hours 30 and 42 would have had a significant effect on the results presented here. It is recognized however that a more ambitious study using a greater data sample should consider the PE forecasts omitted in this study. Although the PE predictors used in the objective PoP forecast technique developed here are vertical velocity, relative humidity and relative humidity trend, an additional predictor, PE QPF, was also examined. PE QPF was found to be a good predictor by itself (4); but results will show that this predictor adds very little to what is already known from the other predictors used.

Results

Table 1 presents the frequency in which measurable precipitation (≥.01") was observed for different ranges of PE forecast relative humidity values verifying during forecast hours 24 to 36 and hours 36 to 48. The relative humidity value used in each case was the higher of either the forecast for the beginning or for the end of the period.

Table 2 presents the frequency in which measurable precipitation was observed for different classes of PE forecast vertical velocity verifying during forecast hours 24 to 36 and 36 to 48. The vertical velocity value used was the higher algebraically of either the forecast for the beginning or the end of the period.

Examination of Table 1 and Table 2 reveals a good relationship for hours 24 to 36 between frequency of measurable precipitation and both forecast relative humidity and forecast vertical velocity. By hours 36 to 48 the relationships, although still apparent, are not as good as for the earlier 12 hour period.

Table 1. Forecast Relative Humidity Versus Frequency of Precipitation

Relative Humidity Forecast*	Frequency of Precipitation (≥.01") 24-36 Hour Period	36-48 Hour Period
90 to 100%	62% (29/47)	50% (19/38)
80 to 89%	52% (12/23)	63% (12/19)
70 to 79%	32% (12/38)	32% (9/28)
60 to 69%	12% (4/34)	6% (3/47)
50 to 59%	8% (4/49)	10% (4/40)
40 to 49%	0% (0/33)	17% (5/30)
30 to 39%	0% (0/18)	0% (0/19)
20 to 29%	0% (0/7)	0% (0/13)

*Relative humidity forecast is higher of either the forecast for the beginning or for the end of the period. Numbers in parenthesis indicates number of cases with precipitation divided by total number of cases.

Table 2. Forecast Vertical Velocity Versus Frequency of Precipitation

Vertical Velocity Forecast*	Frequency of Precipitation ≥ .01" 24-36 Hour Period	36-48 Hour Period
3 to 4	80% (12/15)	46% (6/13)
2 to 2.9	48% (12/25)	38% (9/24)
1 to 1.9	41% (20/49)	41% (19/46)
0 to 0.9	18% (10/55)	17% (10/58)
-1 to-0.1	14% (7/50)	13% (7/55)
-2 to-1.1	0% (0/43)	0% (0/29)
-3 to-2.1	0% (0/8)	0% (0/8)
-4 to-3.1	0% (0/4)	100% (1/1)

*Vertical velocity forecast is in microbars per second and higher algebraically, of either the forecast for the beginning or for the end of the period. Numbers in parenthesis indicates number of cases with precipitation divided by total number of cases.

Figure 1 presents the frequency of measurable precipitation occurrences for different combinations of PE forecast vertical velocity and relative humidity. Results are presented for forecast hours 24 to 36 (figure 1a) and for forecast hours 36 to 48 (figure 1b). Because of the small data sample available, the data was smoothed by grouping cases into selected classes of forecast relative humidity and vertical velocity. The classes of forecast relative humidity and vertical velocity were subjectively determined, separately for hours 24 to 36 and hours 36 to 48. The prime consideration in making the subjective grouping of data was the distribution of frequencies of observed precipitation for sub-groups of relative humidity and vertical velocity combinations for which sufficient data was available. Each sub-group consisted of a range of 10% for relative humidity and a range of 1 microbar per second for vertical velocity (ie. relative humidity 80 to 89% and vertical velocity 1 to 1.9 microbars per second constitute a sub-group). In figures 1 to 3, shading indicates where no data was available. By comparing results in figure 1 to results in table 1 and table 2, it can be seen that better resolution of frequency of observed precipitation is obtained by considering forecasts of vertical velocity and relative humidity together rather than considering either one separately. Note for example that higher values of frequency of observed precipitation and a larger number of cases falling into the zero or near zero frequency of observed precipitation both occur when the predictors are examined together. Intuitively it is believed that the frequency of precipitation should increase gradually from 0% to 100% as you go from low relative humidity and large downward vertical velocity values to high relative humidity and large upward vertical velocity. An exception to this would be the perfect forecast model where all forecasts are either 0% to 100%. The small data sample available here dictated the grouping of data which in some cases resulted in large stepwise changes in frequency of precipitation as you go from one goup to a neighboring group. Hopefully, in the future, a larger data sample will permit a finer data stratification which may show a smoother transition of frequency of precipitation amongst neighboring groups.

Figure 2 presents the frequency of measurable precipitation occurrences for the same classes of PE forecast vertical velocity and relative humidity as used in figure 1a (24 to 36 hours), but now the data is grouped further depending on relative humidity trend expected in the 12 hour forecast period. Figure 2a presents results for increasing or steady relative humidity trend and figure 2b presents results for decreasing relative humidity trend. Decreasing relative humidity trend is defined as a case with relative humidity forecast at the end of the period at least 10% below the relative humidity forecast at the beginning of the period. All other cases are defined as increasing or steady relative humidity trend. Figure 3 presents similar information as figure 2 but for the 36 to 48 hour forecast period.

Examination of figures 2 and 3 reveals that forecast relative humidity trend adds additional predictive information especially at the higher ranges of relative humidity and vertical velocity.

Figure 4 presents the objective PoP forecast technique for use in the second and third forecast period during the cold season in New York City. This figure is developed from figures 1, 2 and 3 with a minimum amount of smoothing. The smoothed probability values presented in figure 4 do not differ by more than 6% from the observed precipitation frequency in the development data.

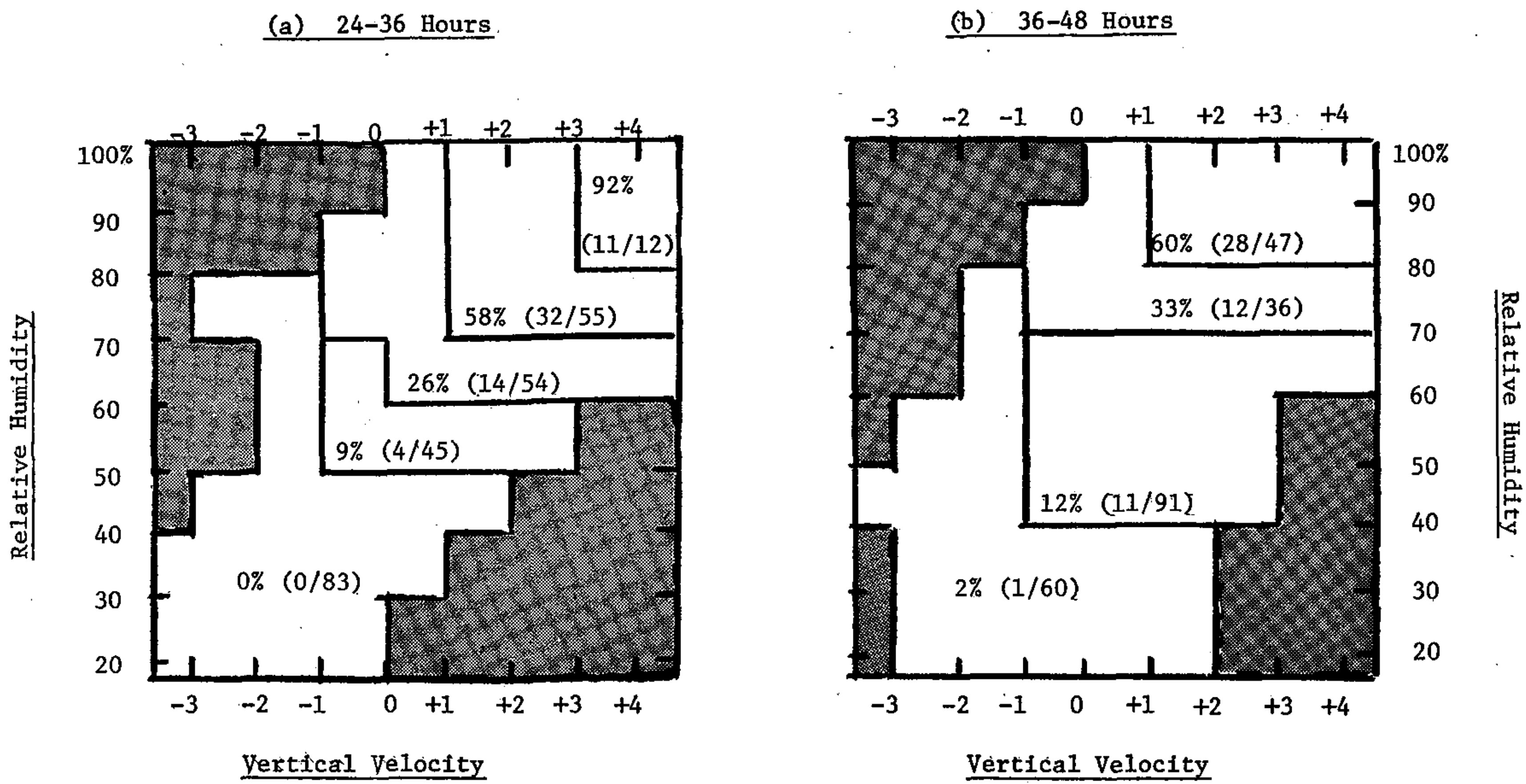

Figure 1. Frequency of measurable precipitation for different combinations of PE forecast vertical velocity and relative humidity. Figure 1 (a) is for forecast hours 24-36 and figure 1 (b) is for forecast hours 36-48. Relative humidity and vertical velocity forecasts are the highest algebraically that occurred at either the beginning or end of the forecast period. Numbers in parenthesis indicates number of cases with precipitation divided by total number of cases. Shading indicates where no data was available.

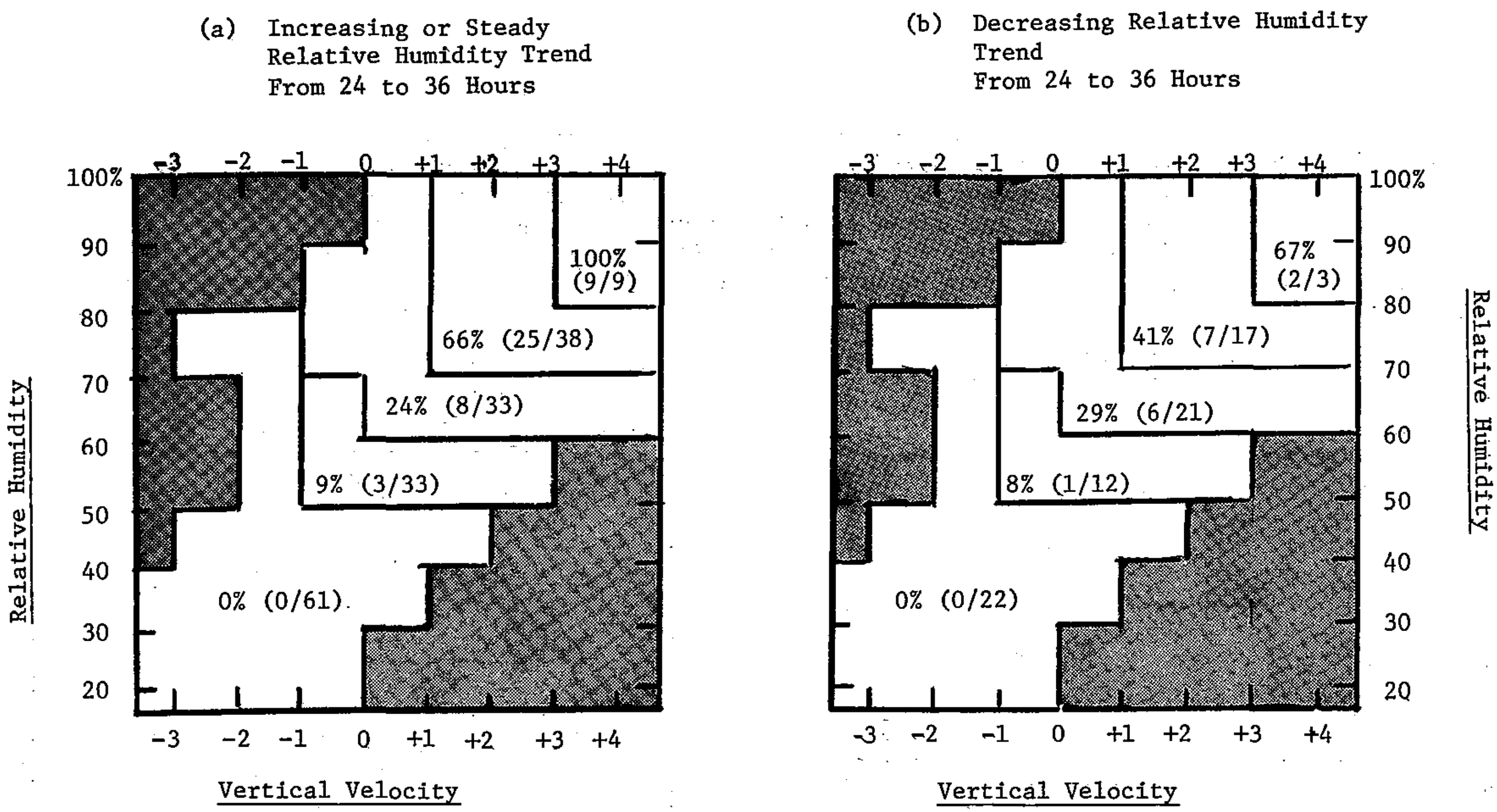

Figure 2. Frequency of measurable precipitation for different combinations of PE forecast vertical velocity, relative humidity and relative humidity trend for the time period 24 to 36 hours. Relative humidity and vertical velocity forecasts are the highest algebraically that occurred at either 24 or 36 hours. Figure 2 (a) presents results for cases with steady or increasing relative humidity trend, figure 2 (b) presents results for cases with decreasing relative humidity trend. Decreasing relative humidity trend is defined as relative humidity forecast at 36 hours at least 10% below the relative humidity forecast at 24 hours; other cases are defined as steady or increasing relative humidity trend. Numbers in parenthesis indicates number of cases with precipitation divided by total number of cases. Shading indicates where no data was available in both figure 2 (a) and figure 2 (b).

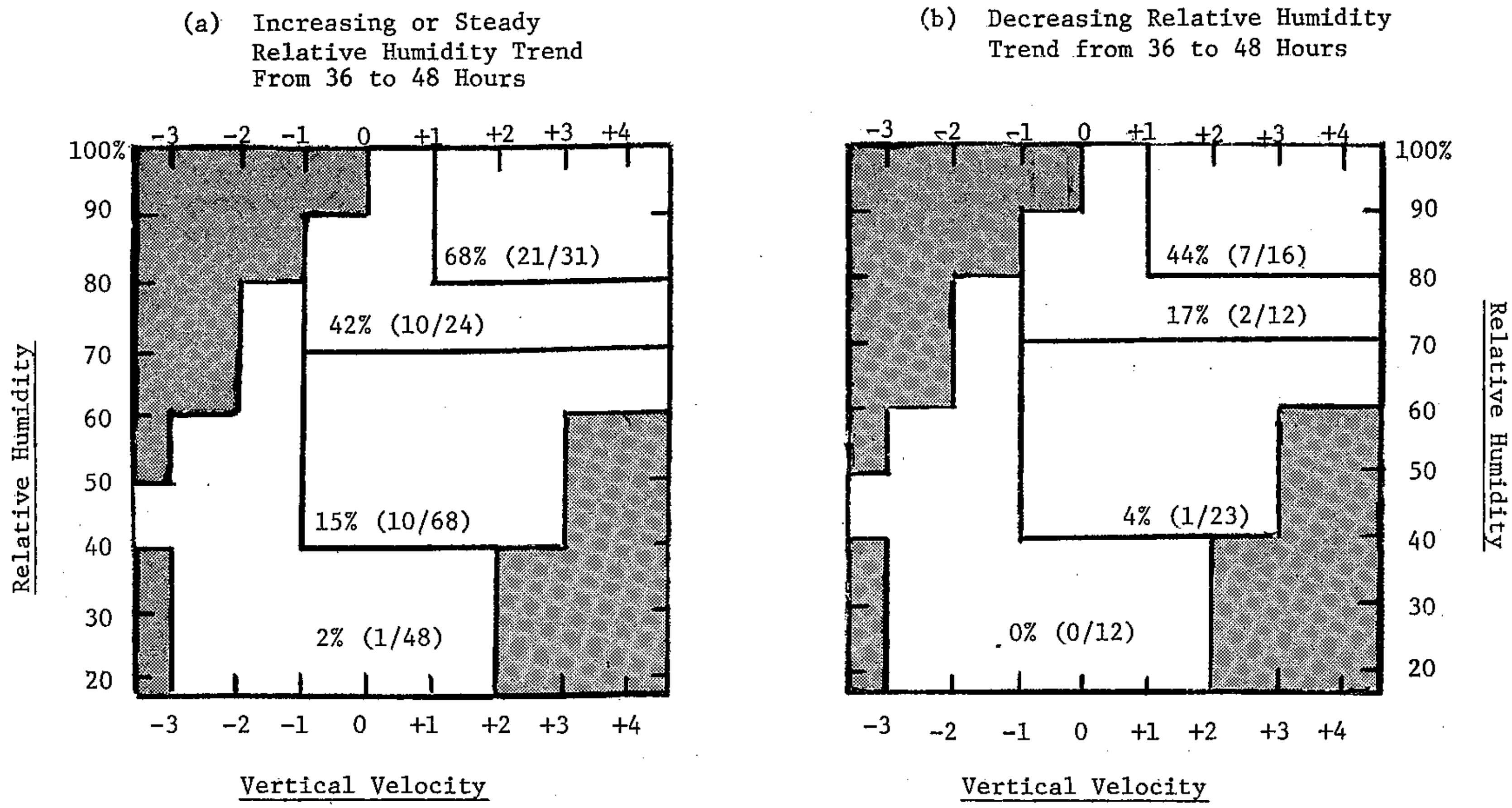

Figure 3. Frequency of measurable precipitation for different combinations of PE forecast vertical velocity, relative humidity and relative humidity trend for the time period 36 to 48 hours. Relative humidity and vertical velocity forecasts are the highest algebraically that occurred at either 36 or 48 hours. Figure 3 (a) presents results for cases with steady or increasing relative humidity trend; figure 3 (b) presents results for cases with decreasing relative humidity trend. Decreasing relative humidity trend is defined as relative humidity forecast at 48 hours at least 10% below the relative humidity forecast at 36 hours; all other cases are defined as steady or increasing relative humidity trend. Numbers in parenthesis indicate number of cases with precipitation divided by total number of cases. Shading indicates where no data was available in both figure 3 (a) and figure 3 (b).

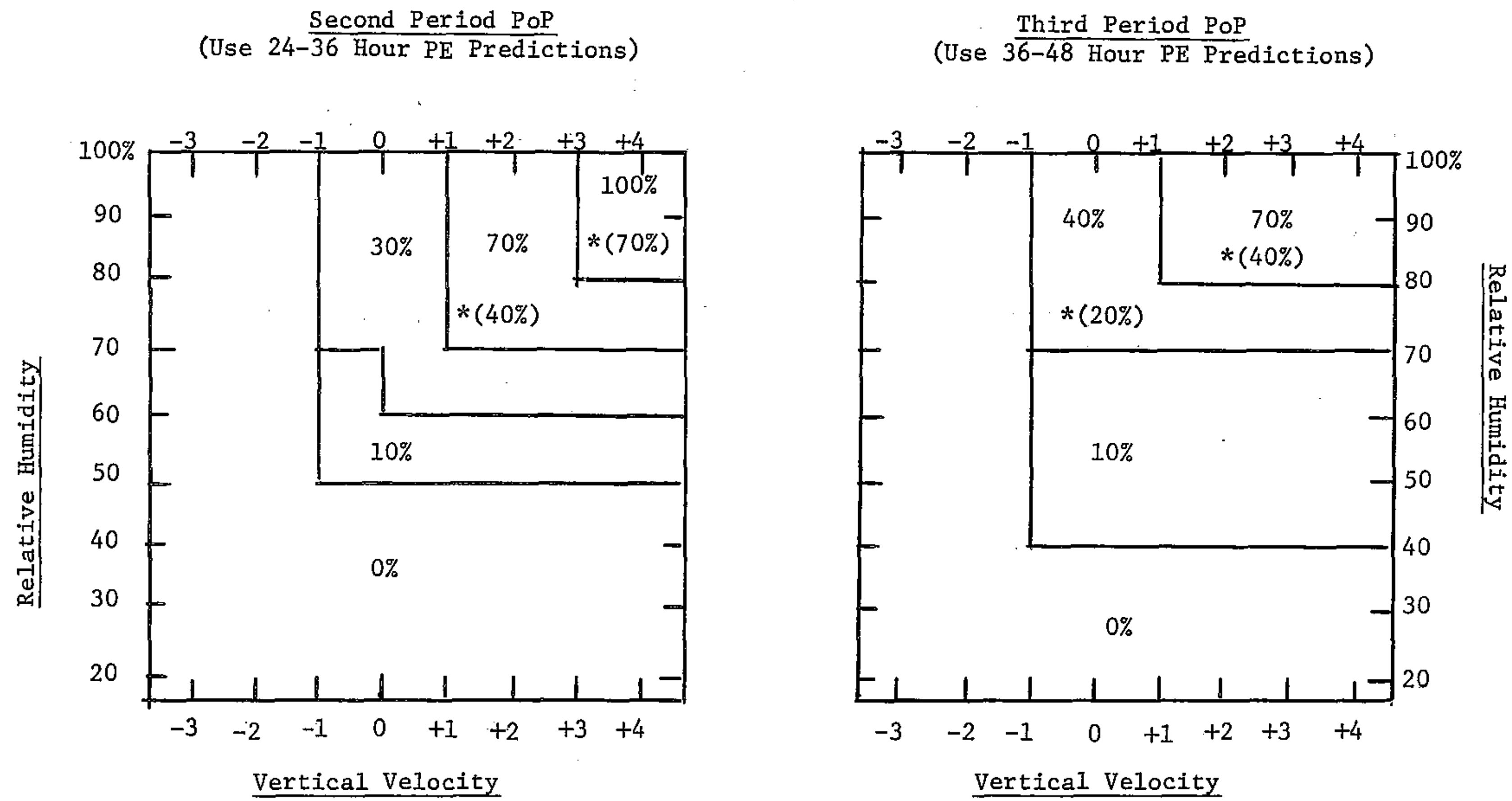

Figure 4. Objective PoP forecast technique for use in NYC, November through March. Relative humidity and vertical velocity forecasts are from PE model 6-hourly output, FOUS-1. (Use highest algebraic values of 6-hourly output valid in forecast period.) *Indicates the effect of relative humidity trend. If the relative humidity prediction for the end of the 12-hour forecast period is at least 10% less than the predicted value at the beginning of the forecast period then use PoP value in parenthesis. If PE QPF of $\geq$.01" valid during the forecast period appears on the FOUS-1 message, then increase forecasts of PoP less than 50% to PoP = 50%, regardless of relative humidity trend.

It can be seen in figure 4 that the importance of considering vertical velocity and/or relative humidity trend forecast increases as the forecast relative humidity value increases.

It was mentioned earlier that knowledge of the PE QPF added little to what was already known from considering the other PE predictors of relative humidity and vertical velocity. This logical finding will now be shown. Using figure 4, frequencies of observed precipitation for PoP forecasts have been obtained. Using table 3 a comparison can be made between those cases in which PE QPF was $\geq$.01" and cases in which PE QPF =0 for similar PoP forecasts. In all cases in which PE QPF was $\geq$.01", the PoP determined from figure 4 was $\geq$ to 40%.

Table 3. Precipitation Frequency For Cases In Which PE QPF is $\geq$.01" Versus Cases In Which PE QPF =0 For Similar PoP Forecast Values.

PoP Forecast (From Fig. 4)	24 to 36 Hours				36 to 48 Hours			
	PE QPF $\geq$.01"		PE QPF = 0		PE QPF $\geq$.01"		PE QPF = 0	
	Cases	Precip* Frequency	Cases	Precip Frequency	Cases	Precip Frequency	Cases	Precip Frequency
100%	6	(6) 100%	3	(3) 100%	-	-- --		
70%	15	(11) 73%	26	(16) 62%	14	(10) 71%	17	(11) 65%
40%	3	(2) 67%	14	(5) 36%	8	(4) 50%	32	(13) 41%

*Number in parenthesis indicates number of cases in which precipitation was observed.

The frequency of observed precipitation when PE QPF was $\geq$.01" is in excellent agreement with what is expected from the PoP forecast generated for these cases from PE forecasts of relative humidity and vertical velocity except for Pop forecasts of 40% in the 24 to 36 hour forecast period. In this latter case the data sample of 3 cases is too small to attach any significance. The precipitation frequency when PE QPF was $\geq$.01" is never less than when PE QPF = 0, but the difference does not exceed 11% for any PoP forecast value except for PoP = 40% in the 24 to 36 hour forecast period.

Considering the evaluation presented here for cases in which PE QPF was $\geq$.01", a modification that should be made when using figure 4 is as follows: If a PE QPF of $\geq$.01" appears on the FOUS-1 message, then increase forecasts of PoP less than 50% to PoP = 50%. A note to this effect appears in the caption of figure 4.

Evaluation of Results

All available PE multilayer moisture model forecasts for JFK were used as dependent data; therefore, the first opportunity to test the results on independent cold season data for JFK will not occur before the winter of 1970 - 71. An estimate can be made, however, of the benefits that could be obtained from the objective technique presented here by an evaluation using the dependent data. For an ideal forecast technique, all PoP forecasts should be 0% or 100% (perfect resolution) while maintaining perfect reliability. In comparing different techniques, the one that yields results closest to the ideal can be considered the best. The frequency of occurrence of PoP forecasts for different PoP values (resolution) for the objective technique and for forecasts issued by NMC and WBFO NYC are presented (table 4).

Table 4. Forecast Verification (Brier Score) and Frequency of Occurrence Of PoP Forecast Values. For N.Y.C. November 1969 through March 1970

PoP Forecast Values	Frequency of Occurrence of PoP Forecasts					
	2nd Period (PE output Hours 24-36)			3rd Period (PE output Hours 36-48)		
	Objective	NMC	WBFO NYC	Objective	NMC	WBFO NYC
0%	33%	9%	16%	26%	6%	10%
10	18	23	32	39	23	4
20		19	26	5	25	26
30	22	16	6		18	5
40	7	10	3	17	9	5
50		8	4		7	4
60		5	6		6	2
70	17	3	3	13	2	5
80		4	2		2	3
90		0	1		1	0
100	4	2	2		0	0
Brier Score (Mean)	.111	.133	.142	.124	.149	.165

The data sample used in computing the resolution for NMC and WBFO NYC is somewhat different than the data sample used for the objective technique. All forecasts considered were issued in the same calendar period, November 1, 1969 through March 31, 1970, but of a possible 302 objective forecasts, 53 were not made in the second period and 68 were not made in the third period because of missing PE forecasts. In order to use the official verification scores, all 302 NMC and WBFO NYC forecasts were included in table 4, regardless of whether an objective forecast was available.

Examining table 4, we see that the objective technique does a better job than WBFO NYC or NMC by showing more resolution. For example in the <u>second period</u> (24-36 hour PE predictions) the objective technique generates a greater frequency of 0% PoP and 100% PoP forecasts and also generates fewer forecasts in the undesirable middle range of 40%, 50% and 60% PoP. The objective technique had a frequency of only 7% in this middle range where NMC had a frequency of 23% and WBFO NYC had a frequency of 13%. Comparing results for the third period, (36-48 hours PE predictions), the objective technique had the greatest frequency of 0% PoP forecasts. In the high PoP range none of the techniques compared issued any forecasts of 100% PoP and only NMC issued any 90% PoP forecasts. The objective technique generated 70% PoP forecasts 13% of the time and this exceeds the frequency of PoP forecasts $>$ 50% (categorical precipitation forecasts) issued by either NMC or WBFO, New York. Comparing the frequency of 3rd period forecasts in the undesirable middle range of 40%, 50% and 60% PoP, we find fewer objective forecasts in this range (17%) than forecasts issued by NMC (22%), but the best performance in this range was achieved by WBFO, New York (11%).

Indications of the potential of the objective forecasts were also made by comparing the skill of these forecasts to the skill of subjective NMC and WBFO, N. Y. forecasts using the mean Brier score as a measure of skill. The mean Brier scores, which are based on both resolution and reliability, were computed considering only those dates on which objective forecasts were made.

NMC and WBFO New York forecasts made on dates in which no objective forecast was made were removed from the data. The results are presented on the bottom of table 4. The Brier scores for the objective technique were lower and therefore superior to NMC and WBFO New York Brier scores for both the second and third forecast period. It is stressed again that since we are dealing with a dependent sample in the objective technique it is not really proper to compare the reliability of the objective forecasts with the NMC and WBFO New York forecasts.

APPLICATION OF TECHNIQUE DEVELOPED FOR NEW YORK CITY TO OTHER LOCATIONS IN THE EAST.

If we assume that any forecast bias that the PE model may have does not vary geographically in the East, and if we assume further that the relationship between PE predictors and frequency of precipitation as shown in Figure 4 does not vary significantly, geographically, then the objective technique developed for NYC should be applicable to other cities in the East. To test these assumptions, PE predictions of relative humidity, vertical velocity and precipitation that appeared in the FOUS-1 message for Philadelphia were used to generate PoP forecasts for that city. In addition to arriving at PoP forecasts for the second and third period, in the public weather forecast, first period PoP forecasts were also generated by applying the second period relationship to PE predictors valid in the first period.

Table 5 presents mean Brier scores for Philadelphia for each of the three periods. In addition mean Brier scores are included for forecasts that were issued by three different Weather Bureau Offices that prepared forecasts for Philadelphia for the same days as the objective forecasts. The National Meteorological Center (NMC) and the Weather Bureau Forecast Office in New York both prepare their forecasts as guidance to be used by the Weather Bureau Office in Philadelphia, which issues the PoP forecasts to the public.

Table 5. Mean Brier Scores for Forecasts Issued for Philadelphia November 1969 through March 1970

Forecaster	1st Period	2nd Period	3rd Period	All Periods
Objective	.105	.119	.140	.121
NMC	.111	.114	.138	.121
NYC	.107	.113	.155	.125
Philadelphia	.088	.107	.144	.113

The results indicate that the objective forecasts had skill, as measured by the Brier score, that was comparable in skill to the forecasts issued by all three Weather Bureau offices and for all three periods. The mean Brier score for the objective technique for all three periods combined was identical to NMC, slightly better than New York and slightly inferior to Philadelphia. It is stressed, however, that the PE data used to generate the objective Philadelphia PoP forecasts were from the same PE model runs as the data used to develop the technique for New York City. Therefore, the objective Philadelphia forecasts are not based on truly independent data.

To alleviate somewhat this dependency of using data from similar PE runs, objective PoP forecasts were generated applying figure 4 to an area farther away from New York City than Philadelphia, but perhaps not too far away to introduce the possibility of geographical bias in the PE model affecting the results. PE predictors of relative humidity and vertical velocity were conviently available for five locations in North Carolina, as tabulated by Robert Muller in an unpublished manuscript (9). Mr. Muller's tabulations were for hours 24 to 36 only, and for the period November 15, 1969 to March 31, 1970. The five locations used in North Carolina were Asheville, Greensboro, Charlotte, Raleigh, and Wilmington. Mr. Muller extracted the PE predictors for these locations from facsimile maps. As indicated earlier, the averaging method in determining vertical velocity forecasts is somewhat different for facsimile presentation than for teletype FOUS-2 messages (6 hourly PE output). The mean Brier score for 1313 forecasts (not independent) made objectively for the five cities combined was .110. This compares to an NMC Brier score for these 5 cities of .106 and a mean Brier score of .104 achieved by the forecasters at the Weather Bureau Forecast Office in Raleigh, N. C. The NMC and Raleigh Brier scores were obtained from monthly mean Brier scores that appear in the official Weather Bureau Verification Forms for the period November 1, 1969 through March 31, 1970. No attempt was made to remove the effects of 47 NMC and Raleigh forecasts made on days in which no PE forecasts were available. The November monthly Brier scores for NMC and Raleigh were given half weight compared to other months since objective forecasts were generated for only the second half of November.

The results presented here for both Philadelphia and North Carolina indicate that it may be possible to develop a general objective PoP forecasting technique applicable to at least the geographical area east of the Appalachians from the Carolinas northward through New England. An attempt made here to use the technique developed specifically for New York City as a more generalized technique showed good results where tested but the results would be more meaningful if they held for independent PE runs. A more appropriate procedure in developing a generalized technique should use development data not only for New York City, as done here, but also for other cities for which the generalized technique is to apply.

CONCLUSIONS:

PE predictions of relative humidity, relative humidity trend, and vertical velocity have been found to be well correlated to frequency of observed precipitation at New York City during the period November 5, 1969 to March 31, 1970. A technique was presented for using these predictors to objectively forecast probability of precipitation. Tests on dependent data showed the objective PoP forecasts for New York City to be better than PoP forecasts prepared by forecasters at NMC and New York City. Further tests showed that the technique can be applied to other locations in the East. The objective PoP forecasting technique can be programmed for computer solution thus yielding a completely automated PoP forecast. Tests will be conducted next winter with independent data. If these tests yield results similar to that obtained for dependent data, then to my knowledge this would be the first time that an objective PoP forecast technique applicable to the second and third forecast period, and capable of being automated, would be available and superior to techniques now used by forecasters.

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